# Laboratory Verification of the Optical Turbulence Sensor (OTS): Particulate Volume Scattering Function and Turbulence Properties of the Flow

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## LONG-TERM GOALS

Our goal is an extensive tank validation of the Optical Turbulence Sensor (OTS). This sensor uses a Hartman optical wavefront sensor to determine turbulence characteristics and to characterize the particulate field. The OTS has recently undergone successful field testing. The ocean trials indicate that the OTS surpasses in many ways current microstructure based instruments to quantify turbulence. Furthermore, it is able to measure particles. As is natural for a novel measurement, a number of questions have arisen with respect to both turbulence measurements and the particle characterization that we address in our effort.

## OBJECTIVES

We have two-fold objectives:

*Particle field characterization*: We plan to develop new methods to fully exploit the raw OTS images, including the projection flow velocity and the near-forward Volume Scattering Function (VSF) of particles that cross the light path. From the measured VSF (Volume Scattering Function) at small angles we can recover the particle size distribution from the field data for larger particles (>100 microns). The simultaneous measurement of the particle size distribution and the flow velocity, using a single instrument, allows for unprecedented determination of particle volume transport on very small scales and turbulence /particle interaction.

*Turbulence characterization*: In this part of the effort we plan to compare independent and highly accurate thermistor and Particle Imaging Velocimetry (PIV) measurements of the Turbulent Kinetic Energy dissipation rate and the temperature dissipation rate with concurrent OTS measurements of the same variables. The studies will be performed in well-controlled tank experiments in the lab. The comparisons will allow detailed characterization of the OTS, including its sensitivity and the applicability of the assumptions of isotropy and homogeneity used in the data processing. By using a stratified tank, we will be able to explore differences between data taken along the vertical versus horizontal propagation paths of the beam. This allows us to address questions of turbulence inhomogeneity. The effects of turbulence and particulate on the OTS measured VSF during field experiment are illustrated in the Figure 1.

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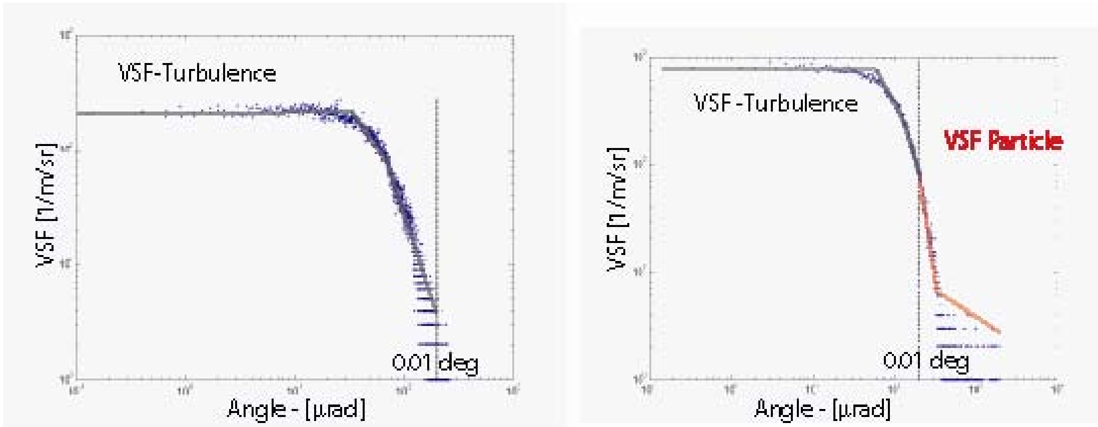


***Figure 1: Volume Scattering function measured by the OTS during Oregon tests. A-a relatively clean water – Approx. 5 Nm offshore; B- particle laden water- Newport harbor***

## APPROACH

We plan on rigorous tank testing of the turbulent and optical quantities measured by the OTS and direct comparison with independent measurements.

- We will carry out **direct measurements (independent of the OTS) of the following turbulent quantities**: turbulent kinetic energy dissipation, temperature variance dissipation rate and the mean flow speed.

- We will carry out direct measurement **(independent of the OTS)** of the **following optical parameters**: particle VSF, beam attenuation and particle scattering coefficient.

This effort will allow estimation of the accuracy of the OTS measurements of turbulence, VSF and the instantaneous projected flow velocity and shear obtained using OTS. The work is carried out by the PI and a PhD student Sarah Woods. In addition in this effort we collaborate with Dr. M Jonasz (MJOpticalTech, particle optics, nephlometer measurements) and Dr. Stramski (UCSD, particle optics). We also collaborate with Dr. A. Fincham (USC, PIV small scale measurements).

## WORK COMPLETED

We have just started our effort. In addition to diffractometer and the OTS the following instruments have been calibrated and will soon be ready for tank measurements:
*Nephlometer VSF measurements* – mostly particle field contribution to the VSF ( between 4 -176 deg). The preliminary testing results - see Figure 2.

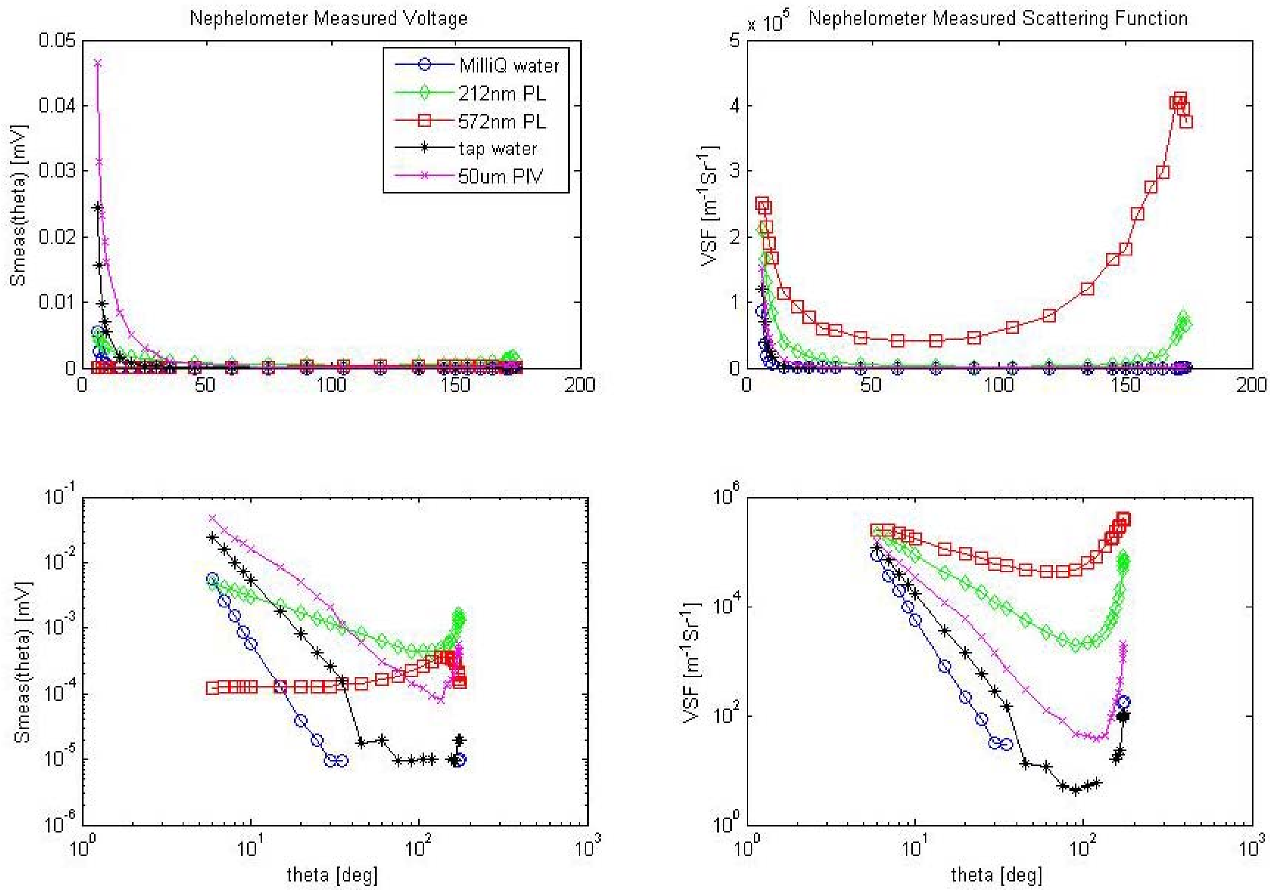


***Figure 2: The nephlometer VSF particle measurements***

*The PIV system to measure flow velocity at small scales* has been setup. We are in the process of PIV final calibrations. The example of the PIV measured 3D velocity field (over 5cmx5cm window) is in the Figure 3.

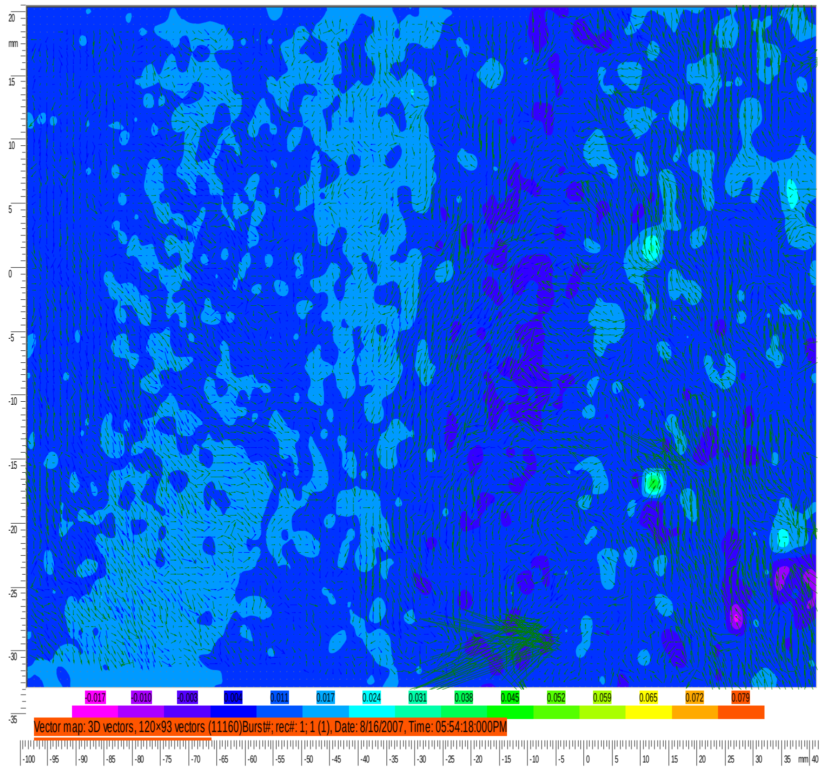


***Figure 3: The initial 3D PIV measured velocity field over 5cmx5cm window. The color corresponds to the flow velocity speeds in/out of the plane.***

## RESULTS

We have setup and calibrated the nephlometer system. We have setup and are in the process of PIV calibration.

## IMPACT/APPLICATIONS

One of the expected results will be the OTS turbulent verification (sensitivity, accuracy of Turbulent Kinetic Energy measurment) and calibration with concurent PIV and fast thermistor data.

We plan on using particles of different sizes and distribution (for example a thin layer like) to study effect of turbulent dispersion: time and spatial scales associated with thin layer dispersion as a function of varyig turbulence strength. Potentially the combined turbulence and particle field measurements would allow for unprecedented studies of particle dynamics and turbulence. One of the outstanding questions is the sediment transport process. Sediment transport results from complicated interactions between turbulent flow, particle motion, and bed configuration. Simultaneous turbulence and particle measurements can help to sort out the most relevant processes as well as providing direct measurements of transport and flux. The OTS measurement method in principle can address a host of questions associated with particle dynamics. Some key questions include the effect of the small scale shear on the formation of thin layers and particle dispersion and aggregation due to ambient flow. These measurements would also lead to better prediction of underwater visibility in coastal environment.

## PUBLICATIONS

D. J. Bogucki, J. A. Domaradzki, C. Anderson, H. W. Wijesekera, R. V. Zaneveld, and C. Moore. 2007. Optical measurement of rates of dissipation of temperature variance due to oceanic turbulence, Optics Express, Vol. 15, Issue 12, pp. 7224-7230. [published, referreed]

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